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INVERTER MODULATION METHOD
[Inbaata no hencho hoho]

Hideo Koo

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INVENTOR	(72):	Hideo Koo
APPLICANT	(71):	Mitsubishi Electric Corporation
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Claim

An inverter modulation method for setting a modulated wave and a carrier wave in a specified mode and that turns an inverter switching element on and off with a gate signal obtained from a comparison of the two waves above to obtain output voltage with variable voltage and variable frequency, which is an inverter modulation method characterized in that when switching from a first mode in which 9 pulses are distributed in a range of 180° of the aforementioned output voltage to a second mode in which 5 pulses are distributed in a range of 120° of the aforementioned output voltage,

a transitional mode, in which the pulse width and pulse spacing of the pair of output pulses present at the 0° and 180° phases of the output voltage in the aforementioned first mode are successively decreased, and the zero output width at the 60° and 120° phases of the output voltage in the aforementioned first mode is

successively decreased to a specific minimum time width determined from the switching capability of the aforementioned switching element, is established between the aforementioned first mode and the second mode.

Detailed explanation of the invention

Industrial application field

The present invention relates to an inverter modulation method such as a three-phase inverter the drives and controls an induction motor, for example.

Prior art

Figures 2-4 explain a conventional type of inverter modulation method described in "Vehicular Induction Motor Inverter Control (Part 2)," 73 in Transactions of the Institute Convention of the Four Electrical Institutes, 1978, for example. Figure 2 is a circuit diagram showing the main circuit configuration of an inverter, Figure 3 is a block diagram showing the control circuit configuration thereof, and Figure 4 is a timing chart showing the operating waveforms thereof. In the figures, (1) is a DC power source, (2) is a switch for turning the main circuit on and off, (3) and (4) are a filter reactor and a filter capacitor, respectively, that constitute an inverted L shaped filter circuit, (5U)-(5Z) are semiconductor switches, such as thyristors, as switching elements that are connected to a three-phase bridge to constitute an inverter, (6) is an induction motor, (7) is a current sensor that senses the current of induction motor (6), and (8) is a pulse generator that senses the rotational frequency of induction motor (6).

(9) is an operating command which is the control input conditions, (10) is a current command generator that generates a current command (Ip) based on the command from operating command (9), (11) is a frequency command generating part that generates a slip frequency command (fsp) based on the command from the same operating command (9), (12) is a current control part that calculates inverter output voltage

(V) from the output of current command generating part (10) and the current IM signal of induction

motor

(6) sensed by current sensor (7), (13) is a slip control part that calculates the slip frequency (fs) of induction motor (6) from the output of frequency command generating part (11) and the current IM signal,

(14) is an adder that calculates the inverter output frequency (F) from the rotational frequency (fM) from pulse generator (8) and from the slip frequency (Fs) from slip control part (13), and (15) is a modulation circuit that outputs a gate signal to semiconductor switches (5U), etc. to [bring] output voltage (V) and output frequency (F) to the target.

The operation will be explained next. A current command (Ip) generated by current command generating part (10) with a command from operating command (9) is compared with current signal (IM) and amplified by current control part (12) to become inverter output voltage (V) to be impressed onto induction motor (6) and is input to modulation circuit (15). Slip frequency instruction (fsp) generated by frequency command generating part (11) at a command from operating command (9) is compared with current signal (IM) and amplified by control part (13) to become the slip frequency (fs) of induction motor (6) and is input to adder (14). Adder (14) receives input of slip frequency (fs) and rotational frequency (fM) from pulse generator (8), and ads when induction motor (6) is accelerating or subtracts when regenerating using the formula below to output inverter output frequency (F) to modulation circuit (15).

$$F = f_M \pm f_s \quad \cdots (1)$$

Modulation circuit (15) sets a sinusoidal U phase modulated wave (16) and a triangular carrier waver (17) produced by a predetermined mode as shown in Figure 4, for example, based on the instructed output frequency (F) and output voltage (V). Then the two waveforms of U phase modulated wave (16) and carrier wave (17) are compared, and a U phase modulated signal (18) that inverts at their point of intersection is obtained. The on/off timing of semiconductor switches (5U) and (5X) shown in Figure 2 is set according to the output level of U phase modulated signal (18).

In the same way, a V phase modulated signal (19) is obtained from a V phase modulated wave, which is

not shown, delayed 120° from the U phase, and carrier wave (17), and the on/off timing of semiconductor switches (5V) and (5Y) is set according to the output level of V phase modulated signal (19). This means that output voltage (20) between the U and V phases, for example, is obtained as inverter output voltage from the actuation of the semiconductor switches based on U phase modulated signal (18) and V phase modulated signal (19).

As the acceleration of induction motor (6) progresses and output frequency (F) rises, the switching frequency of the semiconductor switches constituting the inverter must also be increased correspondingly. However, semiconductor switches have an upper limit to their switching frequency due to switching capacity, usage conditions, etc. For this reason, a method of decreasing the number of output pulses contained in the inverter output voltage waveform in stages as output frequency (F) rises is generally used. For example, on pp. 38-39 of "AC Motor Driving of Electric Vehicles: Inverter Control System," Technical Reports of the Institute of Electrical Engineers of Japan, Part II, No. 251, published June, 1985, a method for switching output pulses in the modes: asynchronous ➪ 21 pulses ➪ 15 pulses ➪ 9 pulses Æ 5 pulses ➪ 3 pulses ➪ 1 pulse is introduced.

Figure 5 shows the waveforms when switching from the 9 pulse to the 5 pulse mode in particular, in the pulse mode switching above. In the figure, the waveform of carrier wave (17) is changed discontinuously at the point in time indicated at (A). That is, the waveform of UV inter-phase output voltage (20) up to time point (A) is a first mode in which 9 pulses are distributed in a range of 180° in a half cycle, and the waveform of UV inter-phase output voltage (20) after time point (A) is a second mode in which 5 pulses are distributed in a range of 120°, which means that switching from the first mode to the second mode is performed at time point (A). Here, (21) in Figure 5 is a sinusoidal V phase modulated wave.

Problems to be solved by the invention

With conventional inverter modulation methods, because they switch directly from a first mode in

which 9 pulses are distributed in a range of 180° to a second mode in which 5 pulses are distributed in a range of 120° as above, the problems are that large pulse width fluctuation occurs, the current or output torque of induction motor (6) changes abruptly, and ride comfort is adversely affected.

The present invention was devised to solve problems such as above. Its objective is to obtain an inverter modulation method that switches smoothly between the modulation modes with 9 pulses and 5 pulses in particular, that can reduce pulse width fluctuation, and can prevent abrupt changes in motor current or output torque.

Means to solve the problems and function

The inverter modulation method pertaining to this invention establishes a transitional mode [as described] below between the first mode and the second mode.

In short, the pulse width and pulse spacing of the pair of output pulses present at the 0° and 180° phases of the output voltage in the first mode are successively decreased, and the output width at the 60° and 120° phases of the output voltage in the aforementioned first mode are successively decreased to a specific minimum time width determined from the switching capability of the switching element. When this transitional mode ends, [control] switches to the second mode. To return to the first mode from the second mode, an operation the inverse of the sequence described above is performed.

Application example

Below, an application example of this invention will be explained with reference to the figures. Figure 1 shows the waveforms in this application example corresponding to the prior [art] Figure 5. In the figure, the same symbols are assigned to the waveforms. In the figure, before time point (A) is the 9 pulse first mode, and the operation is the same as before time point (A) in the prior [art] Figure 5. After time point (B) is the 5 pulse second mode, and the operation is the same as after time point (A) in prior [art] Figure 5. However, compared with the prior [art], [operation] is started from a phase offset by a half cycle with UV inter-phase

output voltage (20). The portion from time point (A) to time point (B) is the transitional mode newly inserted here. To simplify illustration, in Figure 1, it ends with the duration of a half cycle, but actually it will occupy an even longer period and be gradually changed.

Next, the actual operation of modulation circuit (15) in this transitional mode will be explained in accordance with Figure 1. When output frequency (F) reaches the upper limit of the 9 pulse mode (time point (A)), modulation circuit (15) senses this and successively changes the waveform of carrier wave (17) to shift to the transitional mode. That is, it gradually lowers the peak position of carrier wave (17) at phases of UV inter-phase output voltage (20) at 0°, 60°, 120°, 180 (0°), ... Here, as shown in the figure, the portion of specific minimum time width (ΔT) determined from the switching capability of the switching element, e.g., semiconductor switch (5U), remains and the peak position as a triangular wave is lowered. Simultaneously, the time width (Tw) between the relevant peak and the adjacent two peaks of the opposite polarity is gradually widened. The triangular waveform indicated by the partial dotted line in the portion at the 60° phase of the transitional mode represents the waveform of carrier wave (17) in the 9 pulse mode for reference.

The zero output width the 60° and 120° phases of UV inter-phase output voltage (20) is gradually decreased by the waveform manipulation of carrier wave (17) above and finally reaches minimum time width (ΔT) (indicated by (C) in the figure). At the portions of the 0° and 180° phases of UV inter-phase output voltage (20), originally, that is, in the 9 pulse mode, there is a pair of output pulses (22) and (23), but the pulse width and pulse spacing of these output pulses (22) and (23) gradually decrease because of the manipulation of carrier wave (17) and finally disappear (indicated by (D) in the figure). Then the peak position of carrier wave (17) reaches the zero level, the transitional mode ends at the point where time width (Tw) coincides with that [time width] of the 5 pulse mode, and then [control] shifts to the 5 pulse mode. Conversely, to switch from the 5 pulse mode to the 9 pulse mode, operation the inverse of the aforementioned may be performed.

By setting the frequency of the transitional mode appropriately, switching between the 9 pulse first mode and the 5 pulse second mode can be accomplished smoothly and continuously, and abrupt changes in motor current or output torque can be prevented.

Here, for manipulation of the waveform of carrier wave (17) explained with the abovementioned, the required waveform data is stored on a ROM built into modulation circuit (15) and it may be removed as needed.

Also, with the application example above, U phase modulated wave (16) was made a sine wave, but it could also be a square wave. Carrier waver (17) is also not limited to a triangular wave and various waveforms as described in Japanese Kokai Patent Application No. Sho 58[1983]-179176, for example, could also be used.

Effect of the invention

With this invention as above, a specified transitional mode is established between a 9 pulse first mode and a 5 pulse second mode to modulate, so pulse width fluctuation caused by switching between the first and second modes will be slight, and abrupt changes in inverter output are prevented.

Brief description of the figures

Figure 1 is timing charts of waveforms for explaining the modulation operation using an application example of this invention. Figure 2 is a circuit diagram showing the main circuit configuration of an inverter. Figure 3 is a block diagram showing the control circuit configuration thereof. Figure 4 is a timing chart for explaining the basic operation thereof. Figure 5 is a timing chart for explaining conventional modulation operation.

In the figures, (5U)-(5Z) are semiconductor switches as switching elements, (15) is a modulation circuit, (16) is a U phase modulated wave, (17) is a carrier wave, (20) is UV inter-phase output voltage,

(21) is a V phase modulated wave, (22) and (23) are a pair of output pulses, and (ΔT) is minimum time width.

Here, the same symbols in the figures represent the same or corresponding portions.

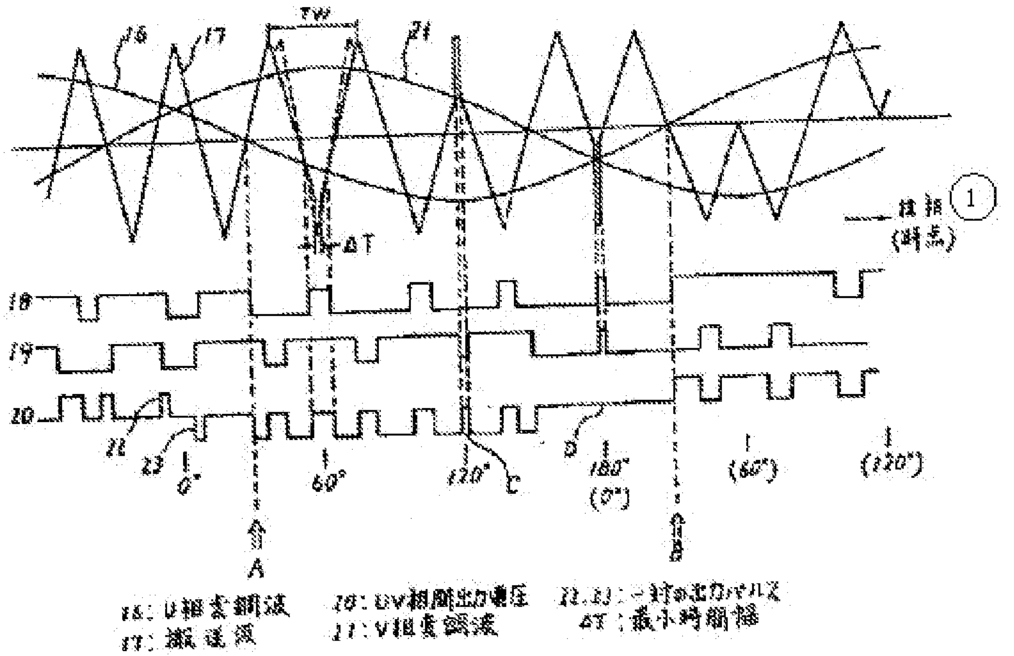

Figure 1

Key: 1 Phase (time point)

16 U phase modulated wave

17 Carrier wave

20 UV inter-phase output voltage

21 V phase modulated wave

22, 23 Pair of output pulses

ΔT Minimum time width

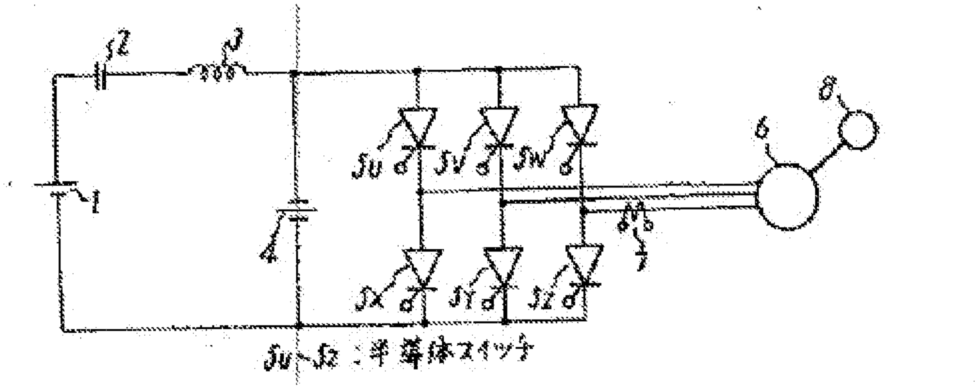

Figure 2

Key: 5U-5Z Semiconductor switches

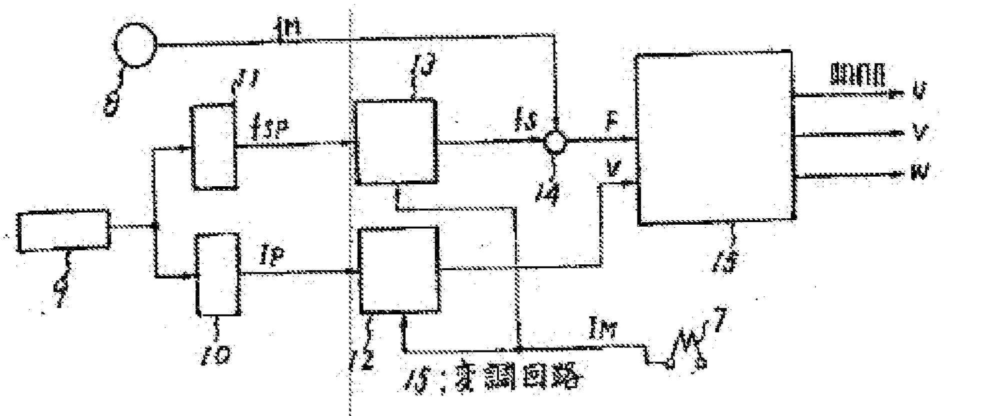

Figure 3

Key: 15 Modulation circuit

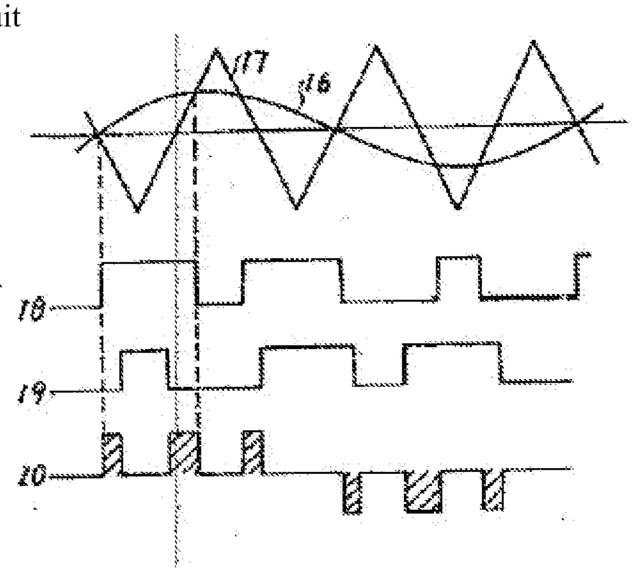

Figure 4

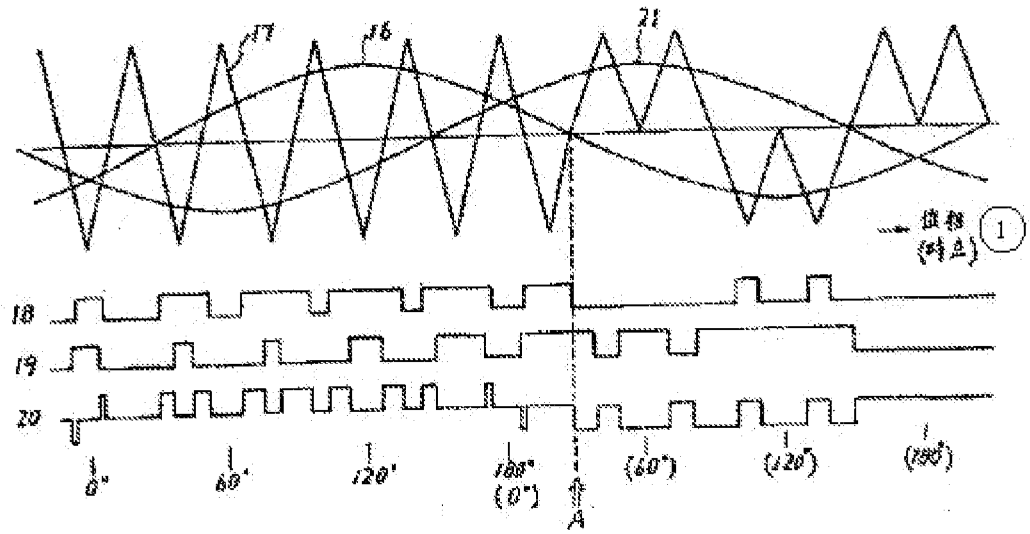

Figure 5

Key: 1 Phase (time point)